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A comparative study of thermodynamic nature of the atmosphere at Dumdum, Calcutta (22.38°N, 88.28°E) on thunderstorm and favourable fair-weather days

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Abstract : In the present study, an attempt has been made to investigate the behaviour (or nature) of the well known thermodynamic parameter ($\theta_{es} - \theta_e$) were θ_{es} and θ_e denote respectively the saturated equivalent potential temperature and the equivalent potential temperature, in two different situations, *viz.* (i) when thunderstorms occur at Dumdum between 1200 UTC and 2400 UTC , (ii) when no thunderstorms occur though the other conditions are favourable The above mentioned favourable conditions mean that the atmosphere is convectively unstable along with positive vertical wind shear

The study, however, has been confined from surface to 500 hPa level. The analysis reveals that the values of the parameter ($\theta_{es} - \theta_e$) at 1200 UTC at 1000 hPa and 850 hPa levels bear a partial indication of the occurrence of thunderstorm at Dumdum in between 1200 UTC and 2400 UTC. But at 0000 UTC, it is partially significant only at 850 hPa level The work has been carried out in two parts, viz,

(i) analysis of the parameters for individual premonsoon month, March, April or May ;

(ii) analysis of the parameters for whole premonsoon period.

Keywords : Convective instability, vertical shear, equivalent potential temperature.

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1. Introduction

Thunderstorm is one of the most powerful agencies which releases the convective instability that gets continuously built-up in the tropical atmosphere.

The essential conditions which favour the development of a meso-scale system like squall line or a synoptic scale system such as cloud cluster etc are as follows :–

(1) Instability in the lower troposphere which is almost always present in the tropics.

(2) Lifting mechanism to produce favourable conditions for releasing this instability.

It is known from the previous study [1] that not only the convective instability but also the vertical wind shear in the environmental wind-field plays an important role in the development of convective clouds, specially the intensity and the depth of the cloud depend on the vertical wind shear in the environmental wind-field. Moreover, the vertical shear of the environmental winds has to match the value of the convective instability for proper development of a large convective cloud [1]. Omotosho [2] showed a strong relationship between thunderstorm occurrence at Kano, Nigeria and static control exerted by the environment through the vertical wind shear over the station.

The thermodynamic parameter ($\theta_{es} - \theta_e$) introduced by Betts [3] in 1974, is a measure of the unsaturation or humidity of the atmosphere, *i.e.* ($\theta_{es} - \theta_e$) can be considered as a measure of moisture departure from the saturated state. It is also a well known fact [4] that thunderstorms are strongly favoured by convective instability, abundant moisture at low levels, strong wind shear and a dynamical lifting mechanism that can release the instability.

In 1961, Krishna Rao [5] suggested a thorough study of the characteristics of thunderstorms in different parts of India as the thunderstorms in different parts of India have different characteristics. It is well known that the occurrence of thunderstorm in India is the highest during March to May. It may be mentioned that premonsoon thunderstorm in India have beneficial effects on agriculture, though in some areas they are associated with disastrous weather.

Most of the premonsoon thunderstorms occur in Calcutta in afternoon hours. So in the present study, the thunderstorms occurring in between 1200 UTC and 2400 UTC at Dumdum, have been considered. The study has been confined from surface to 500 hPa level, because the importance of this level has been stressed by a number of authors, *viz*, Showalter [6], Galway [7], Darkow[8], Fujita *et al* [9]. and the level of cloud development may be taken around 500 hPa. In an earlier work by the present authors [10], the parameter ($\theta_{es} - \theta_e$) was noticed to be more significant below the first lifting condensation level for the occurrence of instantaneous premonsoon afternoon thunderstorms at Ranchi and Agartala, than the other two parameters, *viz*, the convective instability and the resultant vertical shear. The present study aims at investigation of the nature of ($\theta_{es} - \theta_e$) before the occurrence of premonsoon afternoon thunderstorm at Dumdum besides the other two parameters, convective instability and vertical shear of the horizontal wind. During the present study, it has been observed that on all thunderstorm days under consideration, either of the layers, (1000 – 850) hPa and (850 – 700) hPa or both of them are convectively unstable and possess positive vertical wind shear at 1200 UTC at Dumdum, if the thunderstorm occurs there between 1200 UTC and 2400 UTC. So, the above mentioned three parameters, *viz*, convective instability, positive vertical wind shear and ($\theta_{es} - \theta_e$) have been chosen for the present analysis.

The main purpose of the present work is to decide which one of these three parameters carries maximum indication regarding the premonsoon thunderstorm occurrence at Dumdum between 1200 UTC and 2400 UTC and at which of the above mentioned layers (or levels), the parameter is most significant. In order to study the situation of non-thunderstorm days, only those days have been considered on which the atmosphere has similar characteristics as those of thunderstorm days. Those non-thunderstorm days which have positive vertical wind shear for either layer and convective instability for either layer at least at 1200 UTC, have been named here as favourable fair weather days.

2. Data

Daily radiosonde records at 0000 UTC and 1200 UTC for Dumdum (DD) for the years 1988, 1991 and 1993 constitute the data set for this study.

The number of premonsoon thunderstorms and the favourable fair weather situation considered for the layer (1000 – 850) hPa are respectively 7 and 5 for March, 8 and 5 for April, 6 and 12 for May, for the layer (850 – 700) hPa their numbers are respectively 6 and 6 for March, 8 and 20 for April, 8 and 17 for May ; for the layer (700 – 600) hPa, the numbers are respectively 1 and 0 for March, 2 and 12 for April, 3 and 3 for May ; and for the layer (600 – 500) hPa those are respectively 1 and 1 for March, 1 and 5 for April and 3 and 3 for May. It is to be noted that the number of thunderstorms and fair weather days do not add up to the total number of days in month, because only favourable fair weather days have been taken into consideration, besides the thunderstorm days. Only those days with favourable conditions at the upper layers have been analysed which have favourable conditions also at the lower layers either at (1000 – 850) hPa or (850 – 700) hPa.

3. Methodology

In the present work, the parameter, convective instability and the resultant vertical wind shear for different layers, *viz*, (1000 – 850) hPa, (850 – 700) hPa, (700 – 600) hPa and (600 – 500) hPa and $(\theta_{es} - \theta_e)$ at different levels, *viz*, 1000 hPa, 850 hPa, 700 hPa, 600 hPa, 500 hPa, have been analysed for the months, March, April and May individually as well as for the whole pre-monsoon period.

Equivalent potential temperature (θ_e) and saturated equivalent potential temperature (θ_{es}) at different levels have been calculated by the standard formula [11]. The layers for which $\frac{\partial \theta_e}{\partial z} < 0$, where '$z$' denotes the vertical height in metres, are convectively unstable layers. The resultant vertical wind shear is

$$V_S = \sqrt{\left(\frac{\partial U}{\partial Z}\right)^2 + \left(\frac{\partial V}{\partial Z}\right)}$$

where U and V denote the zonal and the meridional components of wind respectively. V_S is assumed to be positive if the resultant wind speed increases with vertical height and it is taken to be negative if the resultant wind speed decreases with vertical height. Here, the resultant wind speed means the speed given in radiosonde data in knots.

For individual month, bar graphs for the mean values of the parameters for thunderstorm occurrence and favourable fair-weather situation have been drawn for different layers for comparison. But only three graphs have been presented here. In Figures (1–3), $\boxed{}$, $\boxed{++++}$ and $\boxed{---}$ denote the bar diagrams of mean $\frac{\partial \theta e}{\partial z}$, mean V_S and mean $(\theta_{es} - \theta_e)$ respectively.

Next, for the whole pre-monsoon period, 90% confidence intervals [12] have been constructed for the above mentioned parameters to estimate them statistically. '90% confidence interval' denotes interval within which there is 90% probability that the actual mean value of the parameter lies. When the number of cases is small, the actual mean has been considered.

4. Observations and Discussion

4.1 Individual months :

The bargraphs (Figures 1–3) show that at 1200 UTC, the parameter $(\theta_{es} - \theta_e)$ at levels 1000 hPa and 850 hPa and at 0000 UTC, the same parameter at 850 hPa behaves more significantly on thunderstorm and favourable fair-weather days than the other two parameters *viz.* mean $\frac{\partial\theta_e}{\partial z}$ and mean V_S. At 1200 UTC, mean $(\theta_{es} - \theta_e)$ is comparatively low at 1000 hPa and 850 hPa levels on thunderstorm days than that on favourable fair-weather situation. At 0000 UTC, it behaves in a similar manner at 850 hPa level only, if thunderstorms occur between 1200 UTC and 2400 UTC at Dumdum.

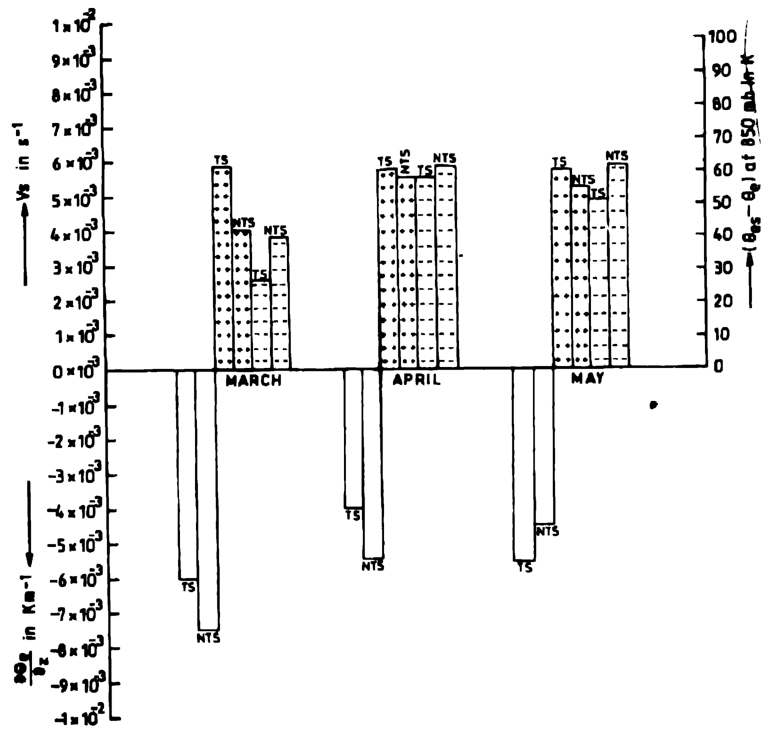

Figure 1. Layers for $\frac{\partial\theta_e}{\partial z}$ and V_S : (850 – 700) hPa, Level for $(\theta_{es} - \theta_e)$. 850 hPa, Time of observation : 0000 UTC.

4.2 Whole premonsoon period :

The 90% confidence intervals [Table 1] constructed for the three parameters at 0000 UTC and 1200 UTC also reveal the fact that for thunderstorm and favourable fair-weather situation, neither the convective instability nor the vertical windshear but the thermodynamic parameter $(\theta_{es} - \theta_e)$ acts as a discriminating parameter, which tallies with the information supplied by the bargraphs (figures 1–3). The values of the parameter $(\theta_{es} - \theta_e)$ are significant at 1000 hPa and 850 hPa at 1200 UTC and at 850 hPa at 0000 UTC.

Table 1. 90% confidence intervals for $\frac{\partial \theta_e}{\partial z}$, V_s and $(\theta_{es} - \theta_e)$ for the whole premonsoon period

Time (UTC)	Layers (hPa)	Convective Instability (Km^{-1})		Vertical Shear (S^{-1})		Levels (mb)	$(\theta_{es} - \theta_e)$ (K).	
		Thunderstorm	Non Thunderstorm	Thunderstorm	Non Thunderstorm		Thunderstorm	Non Thunderstorm
	1000-850	- .010 — - .006	- .008 — - .004	$4 \times 10^{-3} - 7 \times 10^{-3}$	$5 \times 10^{-3} - 7 \times 10^{-3}$	1000	6.4 — 10.5	5.7 — 10 5
0000	850-700	- .008 — - .003	- .007 — - 005	$4 \times 10^{-3} - 7 \times 10^{-3}$	$4 \times 10^{-3} - 6 \times 10^{-3}$	850	13 9 — 26.7	21.5 — 33.1
	700-600	- .008 — - .000	- 003 — - 001	$1 \times 10^{-3} - 8 \times 10^{-3}$	$4 \times 10^{-3} - 8 \times 10^{-3}$	700	6 5 — 24.8	13.8 — 19.5
	600-500	- .001 (actual mean)	- 002 (actual mean)	3×10^{-3} (actual mean)	5×10^{-3} (actual mean)	600	9 749 (actual mean)	data not available
	1000-850	- 011 — - .006	- 012 — - .007	$4 \times 10^{-3} - 6 \times 10^{-3}$	$4 \times 10^{-3} - 5 \times 10^{-3}$	1000	30.5 — 41.5	36 6 — 48.3
1200	850-700	- 013 — - .008	- 009 — - .007	$4 \times 10^{-3} - 5 \times 10^{-3}$	$4 \times 10^{-3} - 5 \times 10^{-3}$	850	16 5 — 25.2	23.0 — 29.7
	700-600	- .004 — - .002	- 005 — - .003	$3 \times 10^{-3} - 6 \times 10^{-3}$	$4 \times 10^{-3} - 5 \times 10^{-3}$	700	14.3 — 21 6	10.5 — 44 4
	600-500	- .007 — - .001	- .003 — - .002	$0 \times 10^{-3} - 7 \times 10^{-3}$	$2 \times 10^{-3} - 4 \times 10^{-3}$	600	6 9 — 17.0	6 8 — 12 1

It is clear from [Table 1] that the 90% confidence intervals for $(\theta_{es} - \theta_e)$ at 1000 hPa and 850 hPa at 1200 UTC and 0000 UTC are not strictly non-overlapping. But these levels are being taken as significant as the overlapping zone is relatively small. Only those portions of the intervals have been considered here conclusive which are strictly non-overlapping, and the

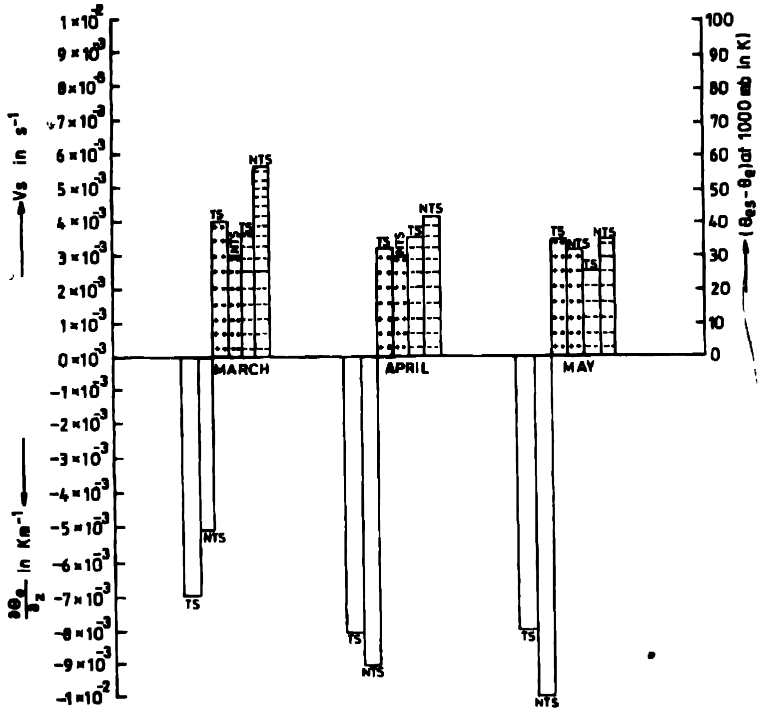

Figure 2. Layers for $\frac{\partial \theta_e}{\partial z}$ and V_S : (1000 - 850) hPa, Level for $(\theta_{es} - \theta_e)$. 1000 hPa, Time of observation 1200 UTC.

overlapping regions have been neglected. The non-overlapping regions provide an estimate of the values of $(\theta_{es} - \theta_e)$ at different levels and one may be 90% confident about the occurrence of thunderstorm if the value of $(\theta_{es} - \theta_e)$ lies in the non-overlapping region for thunderstorm. On the otherhand, if it falls within the non-overlapping region for favourable fair-weather situation, then there is a 90% probability that the weather will remain fair even if other conditions are favourable for thunderstorm occurrence. But for the value belonging to the overlapping region for a situation, no inference has been drawn regarding the parameter $(\theta_{es} - \theta_e)$.

The significant intervals for $(\theta_{es} - \theta_e)$ are as follows :

(A) At 1200 UTC

(i) 30.5 K – 36.6 K at 1000 hPa for thunderstorm,

(ii) 41.5 K – 48.3 K at 1000 hPa for favourable fair-weather situation,

(iii) 16.5 K – 23.0 K at 850 hPa for thunderstorm,

(iv) 25.2 K – 29.7 K at 850 hPa for favourable fair-weather situation.

(B) At 0000 UTC

(i) 13.9 K – 21.5 K at 850 hPa for thunderstorm,

(ii) 26.8 K – 33.1 K at 850 hPa for favourable fair-weather situation.

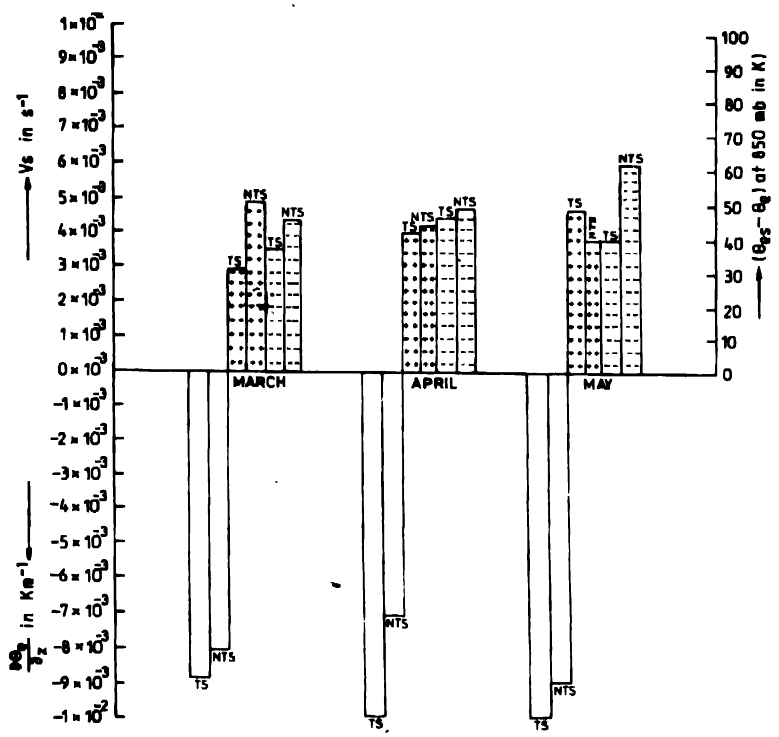

Figure 3. Layers for $\frac{\partial \theta e}{\partial z}$ and V_S (850 – 700) hPa. Level for ($\theta_{es} - \theta_e$) 850 hPa. Time of observation : 1200 UTC.

The neglected (overlapping) regions for ($\theta_{es} - \theta_e$) are as follows :

(A) AT 1200 UTC

(i) 36.7 K – 41.4 K at 1000 hPa,

(ii) 23.1 K – 25.1 K at 850 hPa.

(B) AT 0000 UTC

(i) 21.6 K – 26.7 K at 850 hPa.

5. Conclusion

The purpose of this study, as has been stated earlier, is to search for parameters which may be considered responsible for the development and occurrence of thunderstorms at Dumdum in between 1200 UTC and 2400 UTC.

It is interesting to find that for Dumdum, the thermodynamic parameter ($\theta_{es} - \theta_e$) acts partially as one of the indicators at 1000 hPa and 850 hPa at 1200 UTC for the occurrence of thunderstorms in between 1200 UTC and 2400 UTC. In the morning, *i.e.* at 0000 UTC, the parameter ($\theta_{es} - \theta_e$) is partially significant only at 850 hPa level. Hence, it may be concluded that for prediction of occurrence of thunderstorm at Dumdum in between 1200 UTC and 2400 UTC, the observations at 1200 UTC upto 850 hPa level are much more informative regarding the parameter ($\theta_{es} - \theta_e$).

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